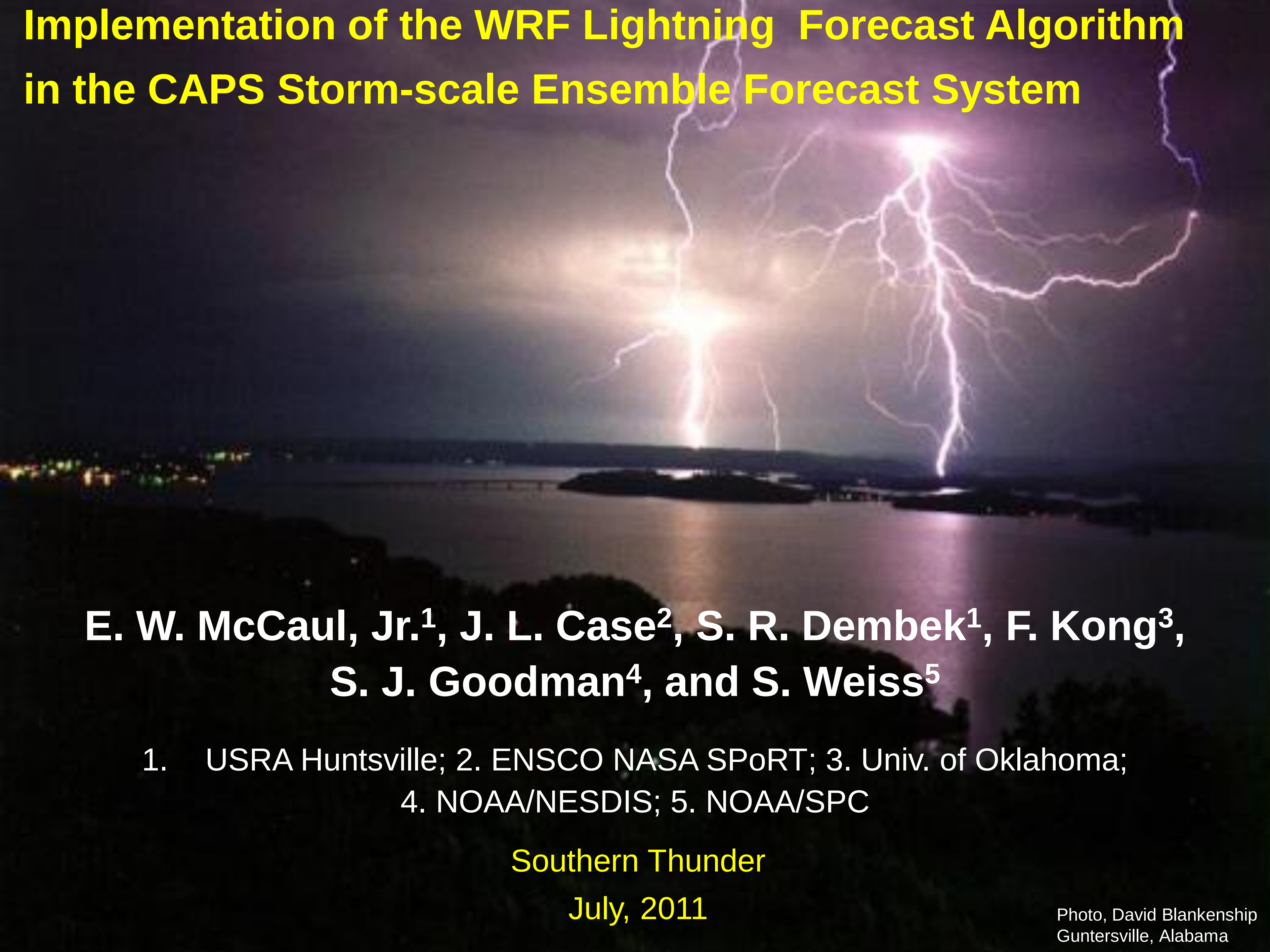


Implementation of the WRF Lightning Forecast Algorithm in the CAPS Storm-scale Ensemble Forecast System

E. W. McCaul, Jr.[1], J. L. Case[2], S. R. Dembek[1], F. Kong[3], S. J. Goodman[4], and S. Weiss[5]

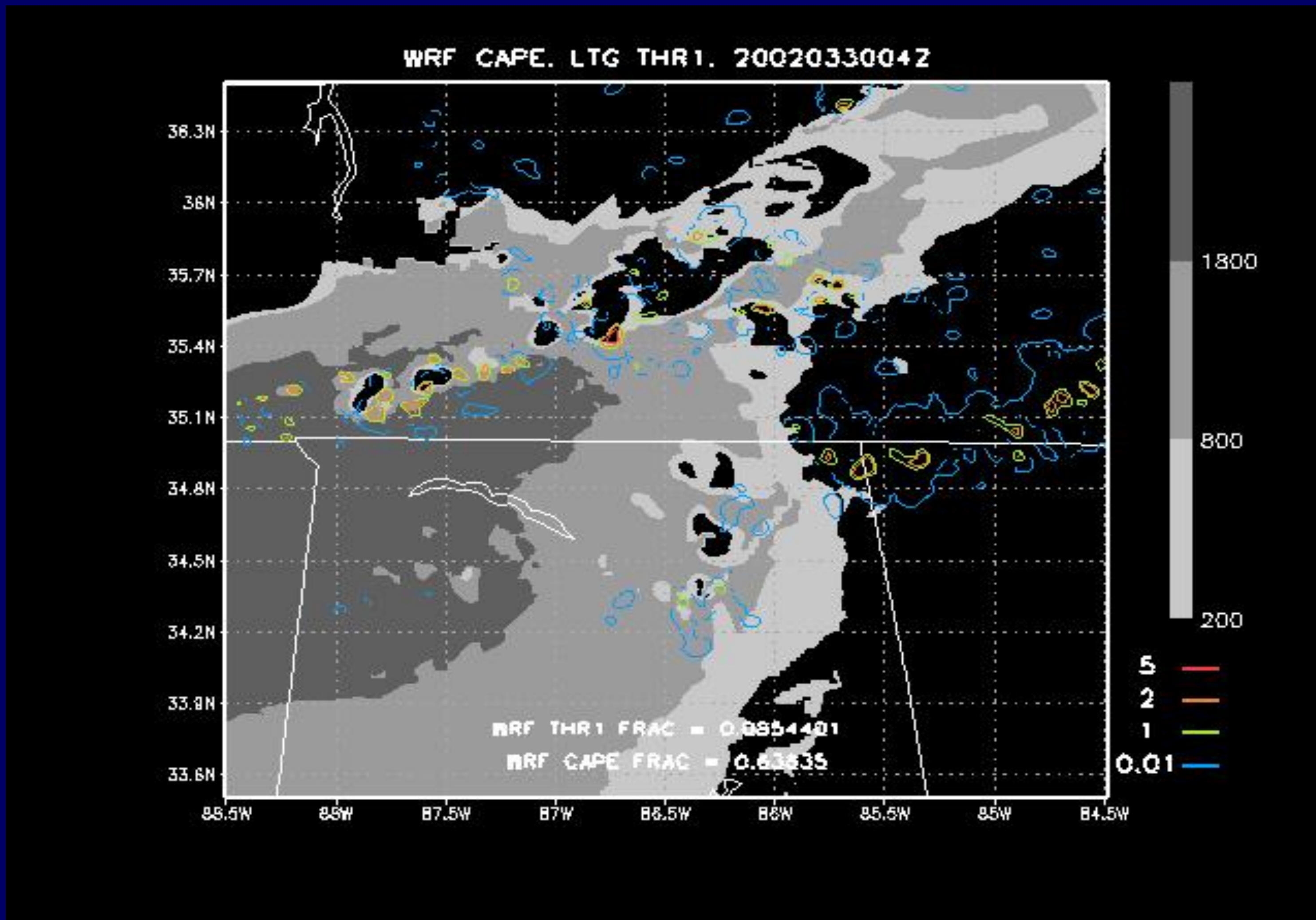
1. USRA Huntsville; 2. ENSCO NASA SPoRT; 3. Univ. of Oklahoma; 4. NOAA/NESDIS; 5. NOAA/SPC

Southern Thunder

July, 2011

Photo, David Blankenship
Guntersville, Alabama

Motivation: Compare coverage CAPE vs LFA Threat 1



LFA Objectives

Given LTG link to large ice, and a cloud-scale model like WRF, which prognoses hydrometeors, LFA seeks to:

1. Create WRF forecasts of LTG threat (1-36 h), based on simple proxy fields from explicitly simulated convection
2. Construct a calibrated threat that yields accurate quantitative peak flash rate densities for the strongest storms, based on LMA total LTG observations
3. Provide robust algorithm for use in making proxy LTG data, and for potential uses with DA

WRF Lightning Threat Forecasts:

LFA Methodology

1. Use high-resolution 2-km WRF simulations to prognose convection for a diverse series of selected case studies
2. Evaluate two proxy fields:
   - graupel fluxes at -15C level (FLX, handles t variations);
   - vertically integrated ice (VII, handles areal coverage)
3. Calibrate these proxies using peak total LTG flash rate densities from NALMA vs. strongest simulated storms; relationships ~linear; regression line passes through origin
4. Truncate low threat values to make threat areal coverage match NALMA flash extent density obs
5. Blend proxies to achieve optimal performance

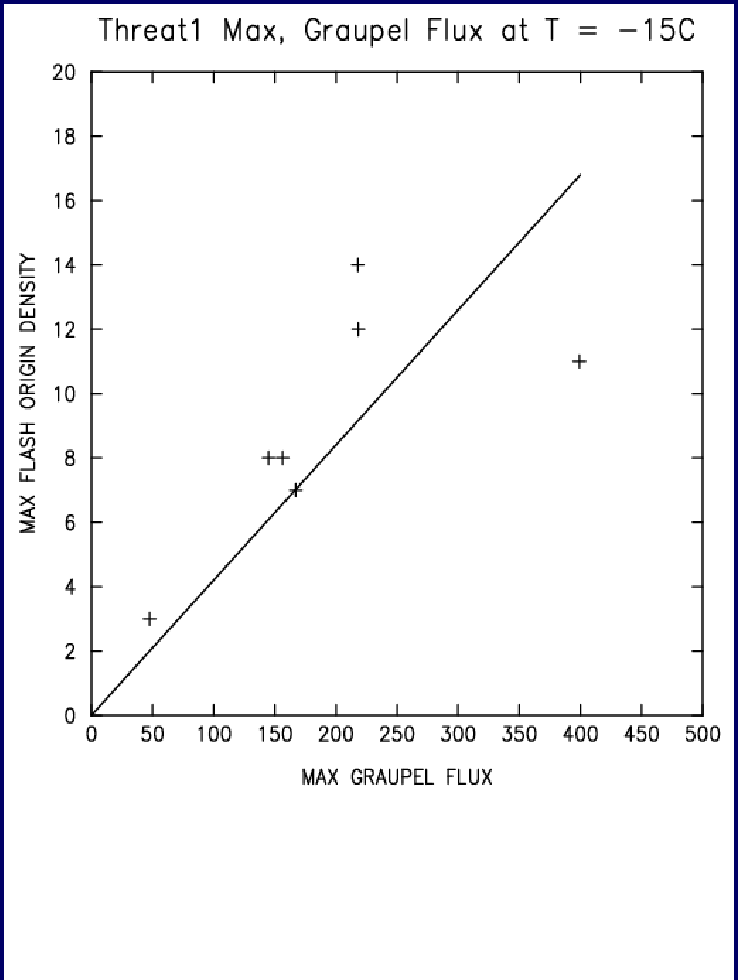
Calibration Curve

Threat 1 (FLX)

$F_1 = 0.042$ FLX

$F_1 > 0.01$

$r = 0.67$



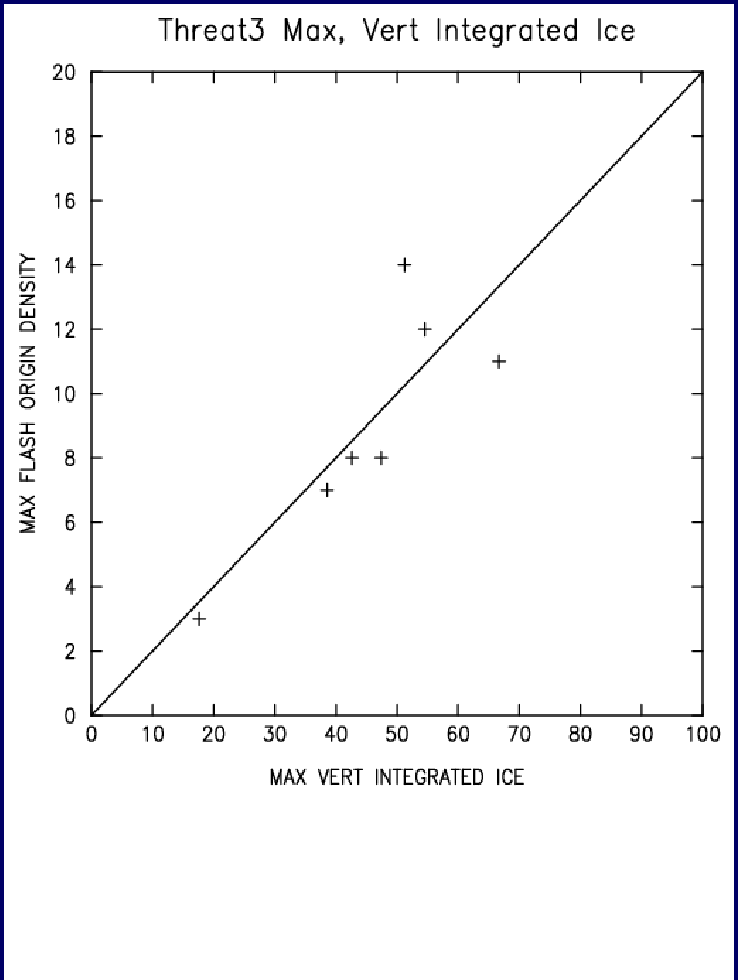
Units of F_1 are fl/km^2/5 min

Calibration Curve

Threat 2 (VII)

$F_2 = 0.2$ VII
$F_2 > 0.4$

r = 0.83



Units of F_2 are $fl/km^2/5$ min

LTG Threat Methodology: Advantages

- Methods based on LTG physics; should be robust and regime-independent
- Can provide quantitative estimates of flash rate fields; use of thresholds allows for accurate threat areal coverage
- Methods are fast and simple; based on fundamental model output fields; no need for complex electrification modules

LTG Threat Methodology: Disadvantages

- Methods are only as good as the numerical model output; models usually do not make storms in the right place at the right time; saves at 15 min sometimes miss LTG jump peaks
- Small number of cases, lack of extreme LTG events means uncertainty in calibrations
- Calibrations should be redone whenever model is changed, or error bars acknowledged regarding sensitivities to grid mesh, model microphysics (to be addressed here and in future)

WRF Configuration (typical)
30 March 2002 Case Study

- 2-km horizontal grid mesh
- 51 vertical sigma levels
- Dynamics and physics:
  - Eulerian mass core
  - Dudhia SW radiation
  - RRTM LW radiation
  - YSU PBL scheme
  - Noah LSM
  - WSM 6-class microphysics scheme (graupel; no hail)
- 8h forecast initialized at 00 UTC 30 March 2002 with AWIP212 NCEP EDAS analysis;
- Also used METAR, ACARS, and WSR-88D radial vel at 00 UTC;
- Eta 3-h forecasts used for LBC's

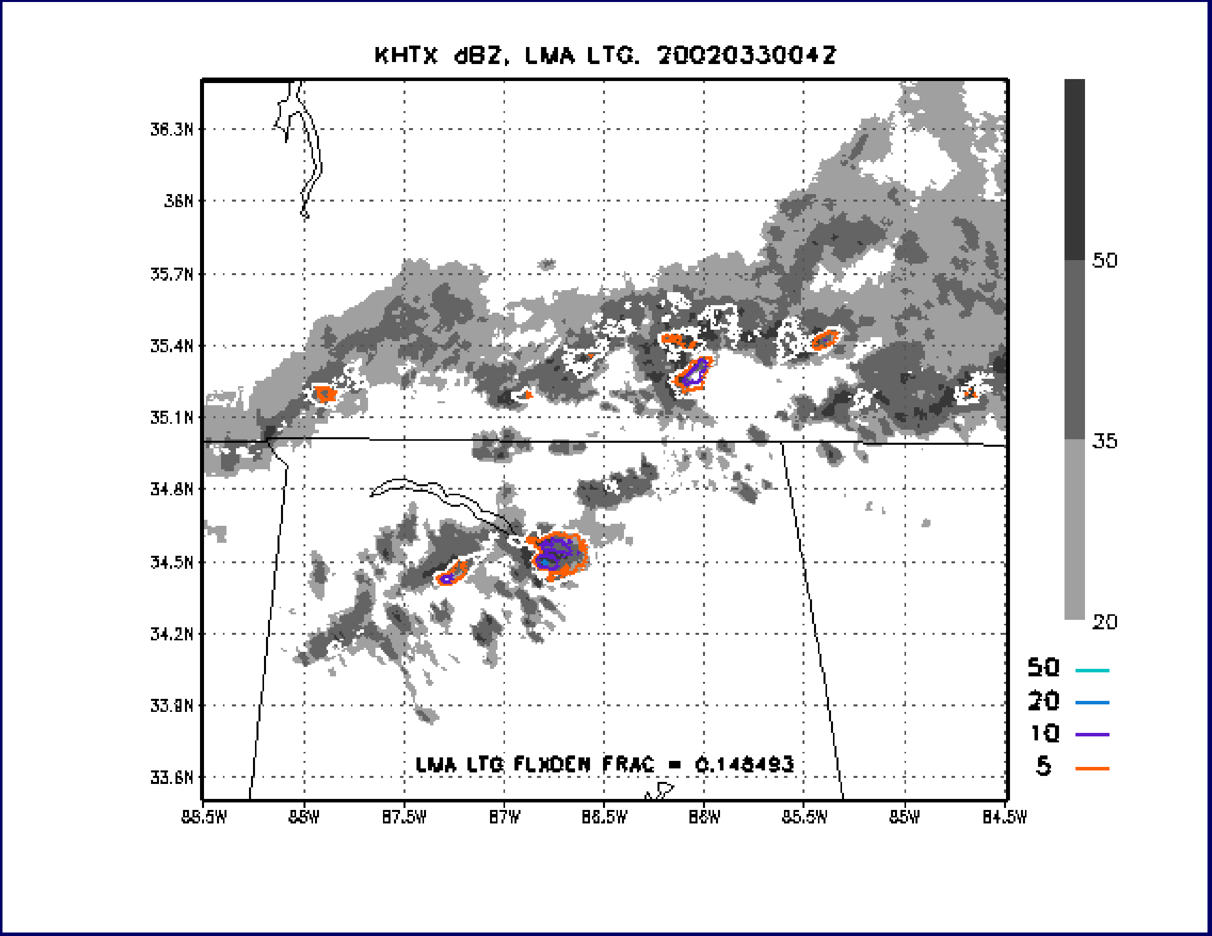
WRF Lightning Threat Forecasts:

Case: 30 March 2002

Squall Line plus Isolated Supercell

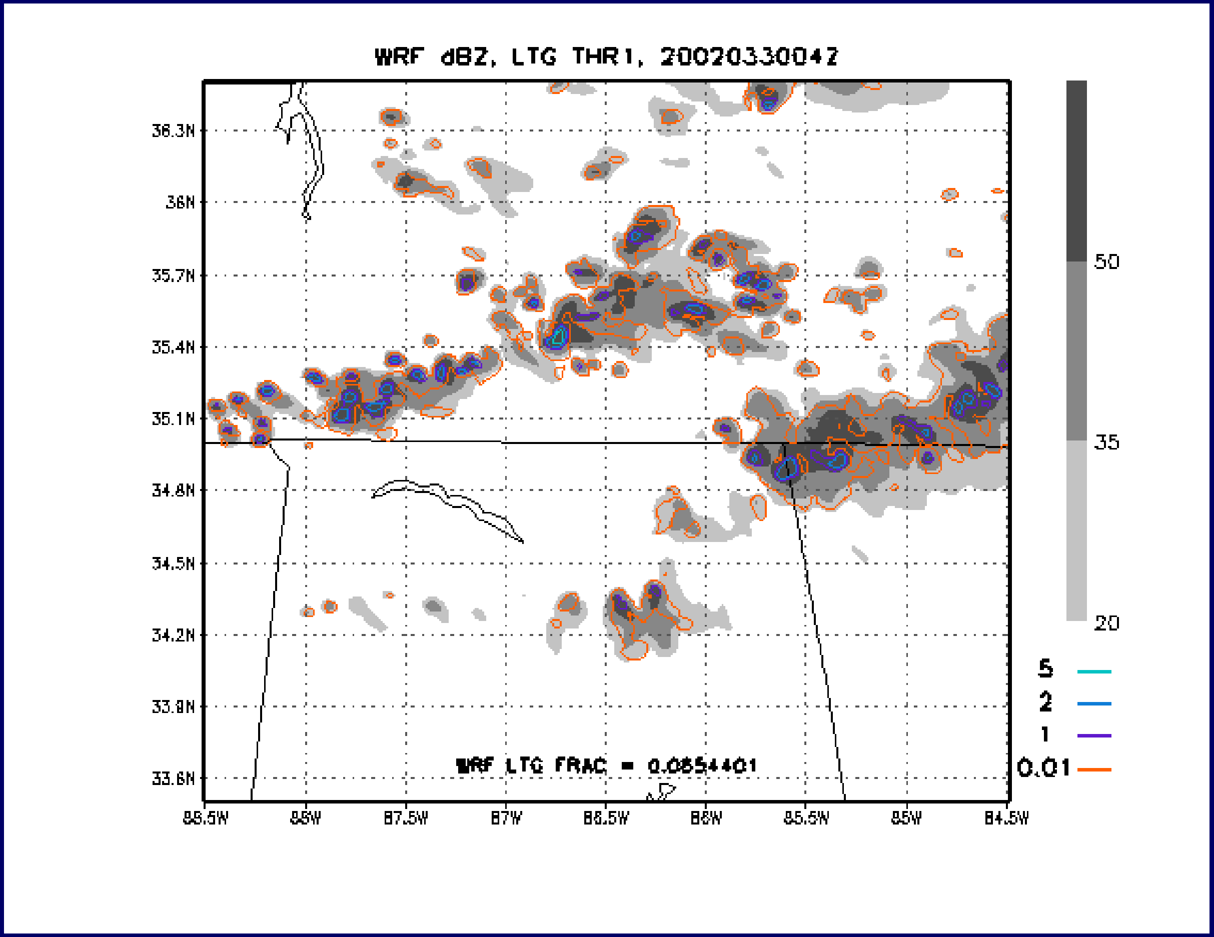
Ground truth: LTG flash extent density + dBZ

30 March 2002, 04Z



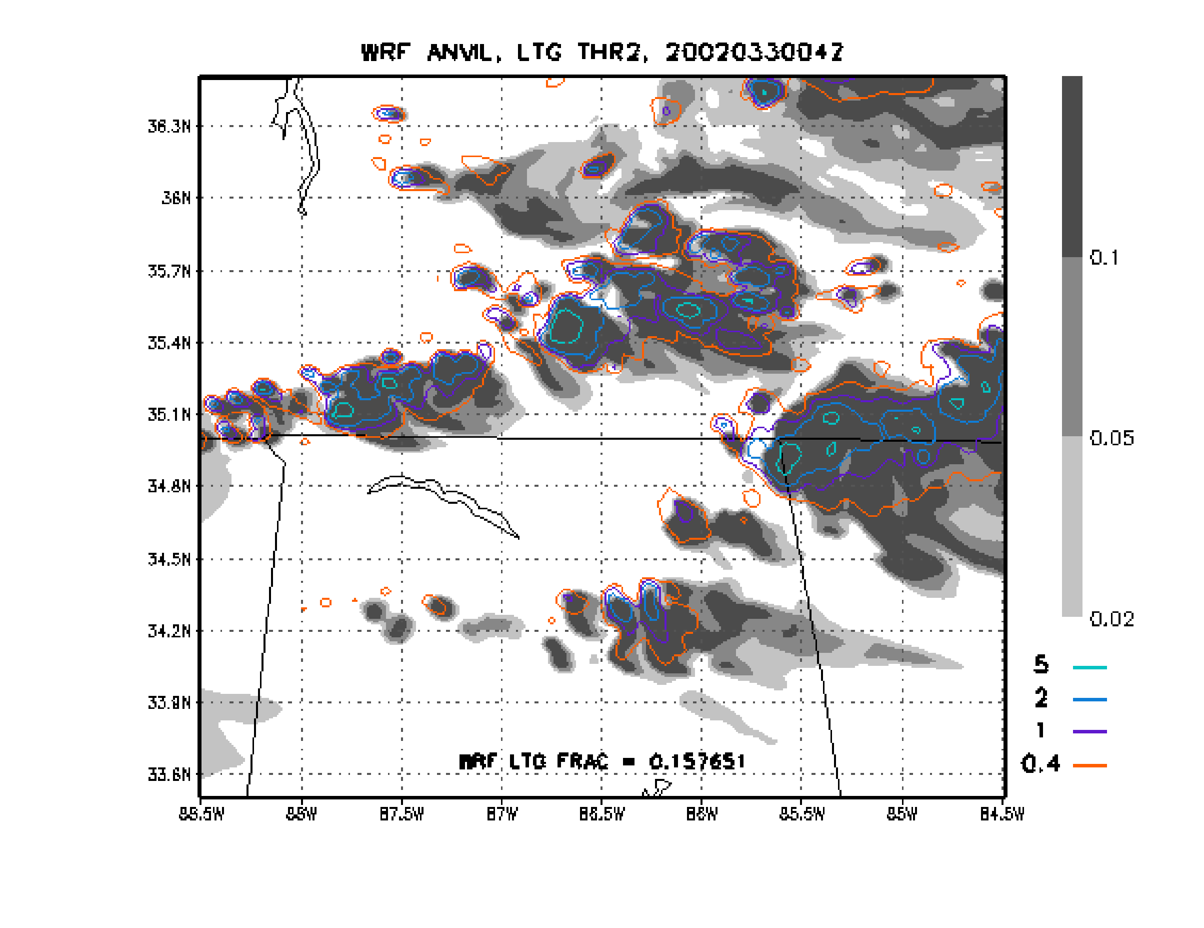
WRF forecast: Threat 1 (FLX) + 6km dBZ

30 March 2002, 04Z



WRF forecast: Threat 2 (VII) + 10 km anvil ice

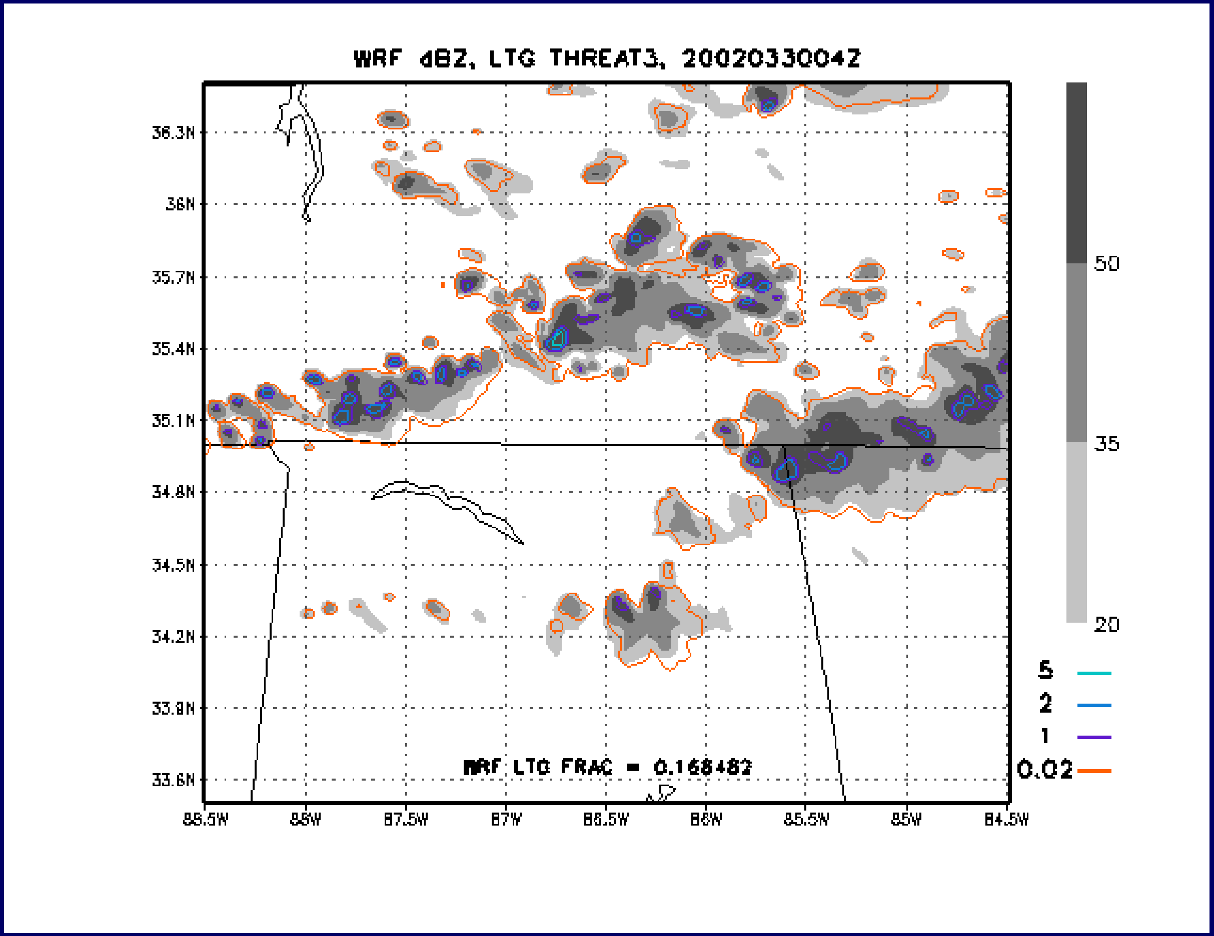
30 March 2002, 04Z



Construction of blended threat:

1. Threat 1 and 2 are both calibrated to yield correct peak flash densities
2. The peaks of threats 1 and 2 also tend to be coincident in all simulated storms, but threat 2 covers more area
3. Thus, weighted linear combinations of the 2 threats will also yield the correct peak flash densities
4. To preserve most of time variability in threat 1, use large weight w_1
5. To preserve areal coverage from threat 2, avoid very small weight w_2
6. Tests using 0.95 for w_1, 0.05 for w_2, yield satisfactory results

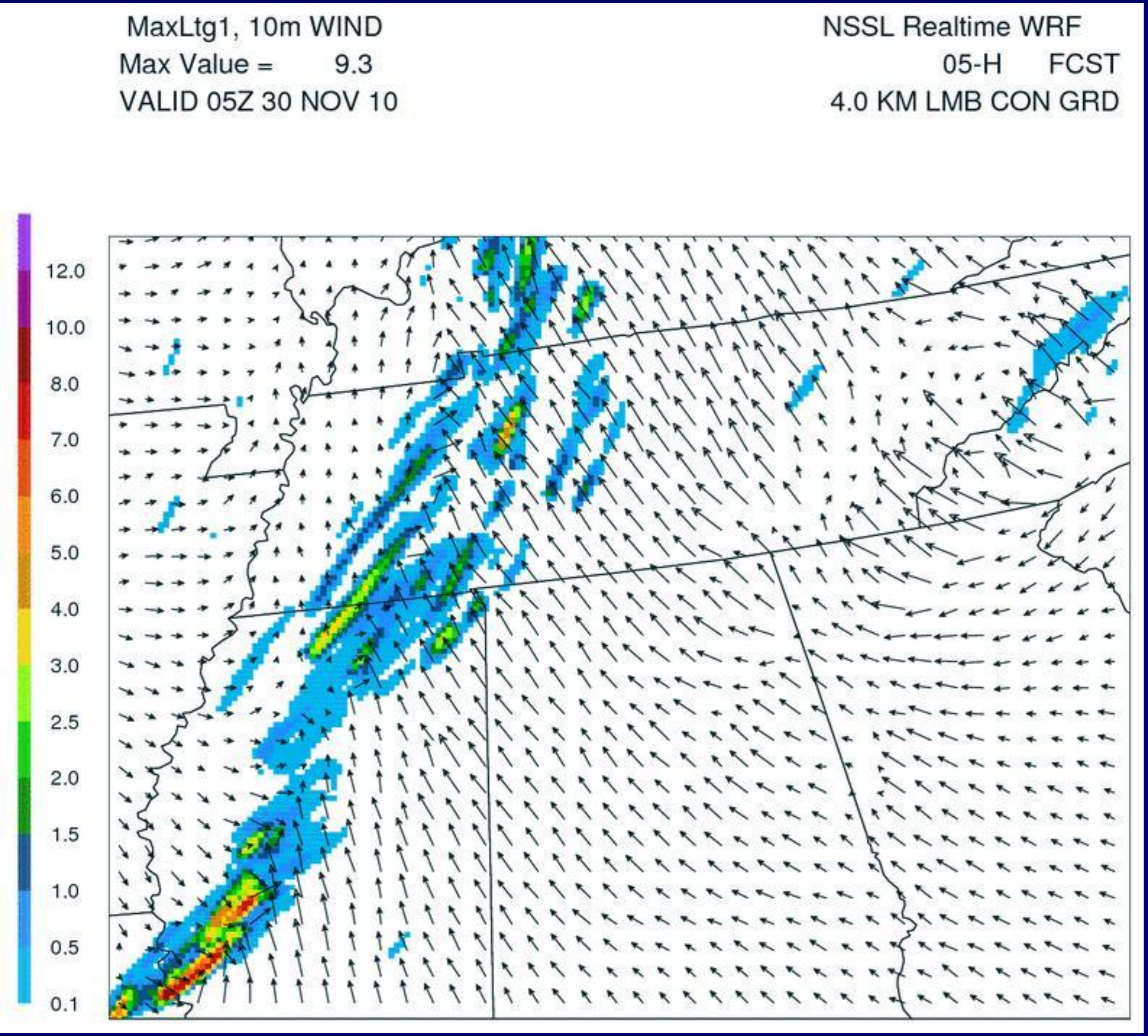
Blended Threat 3 + dBZ: 2002033004Z



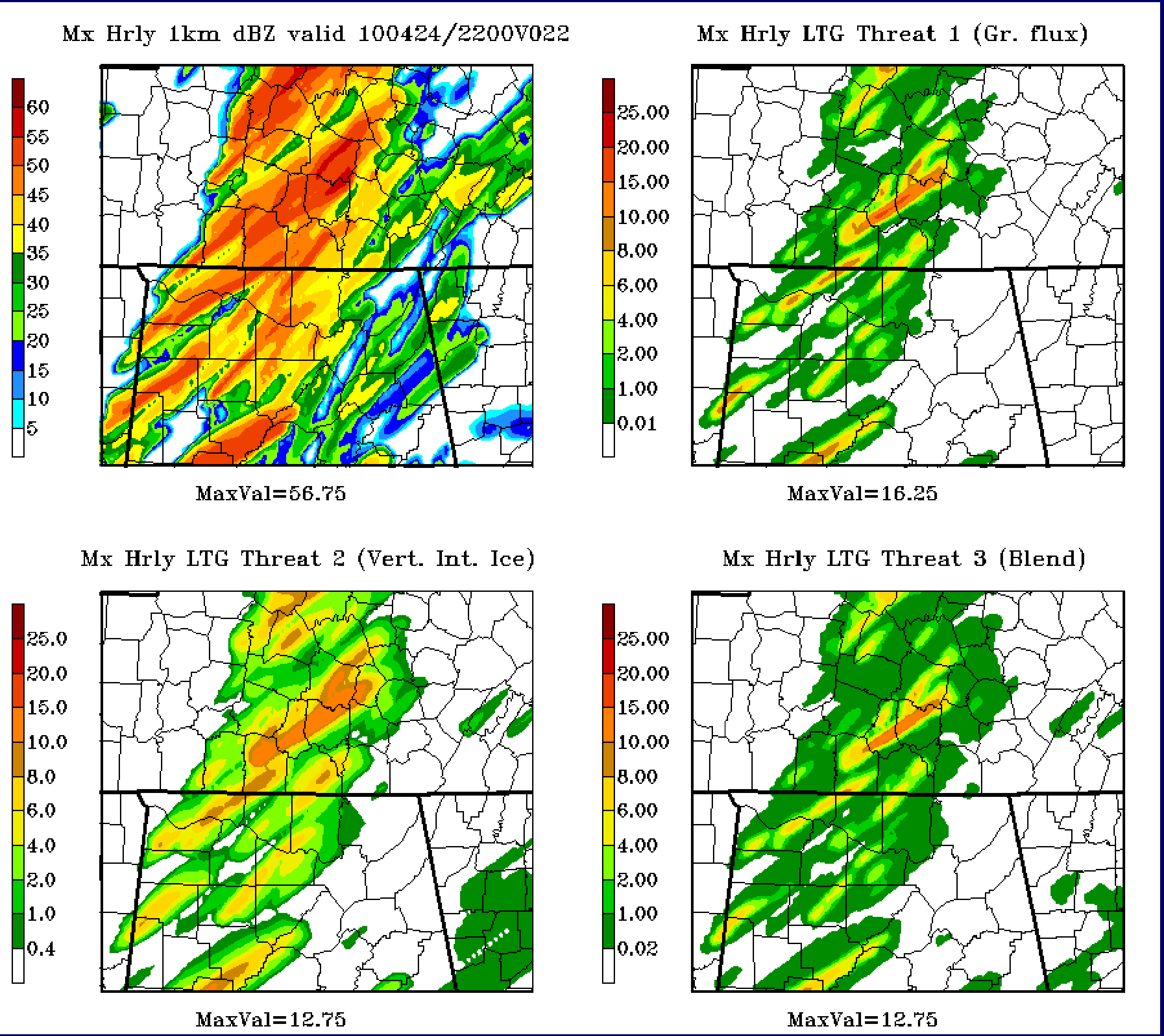
General Findings:

1. LTG threats 1 and 2 yield reasonable peak flash rates
2. LTG threats provide more realistic spatial coverage of LTG than that suggested by coverage of positive CAPE, which overpredicts threat area, especially in summer
   - in AL cases, CAPE coverage ~60% at any t, but our LFA, NALMA obs show storm coverage only ~15%
   - in summer in AL, CAPE coverage almost 100%, but storm time-integrated coverage only ~10-30%
   - in frontal cases in AL, CAPE coverage 88-100%, but squall line storm time-integrated coverage is 50-80%
3. Blended threat retains proper peak flash rate densities, because constituents are calibrated and coincident
4. Blended threat retains temporal variability of LTG threat 1, and offers proper areal coverage, thanks to threat 2

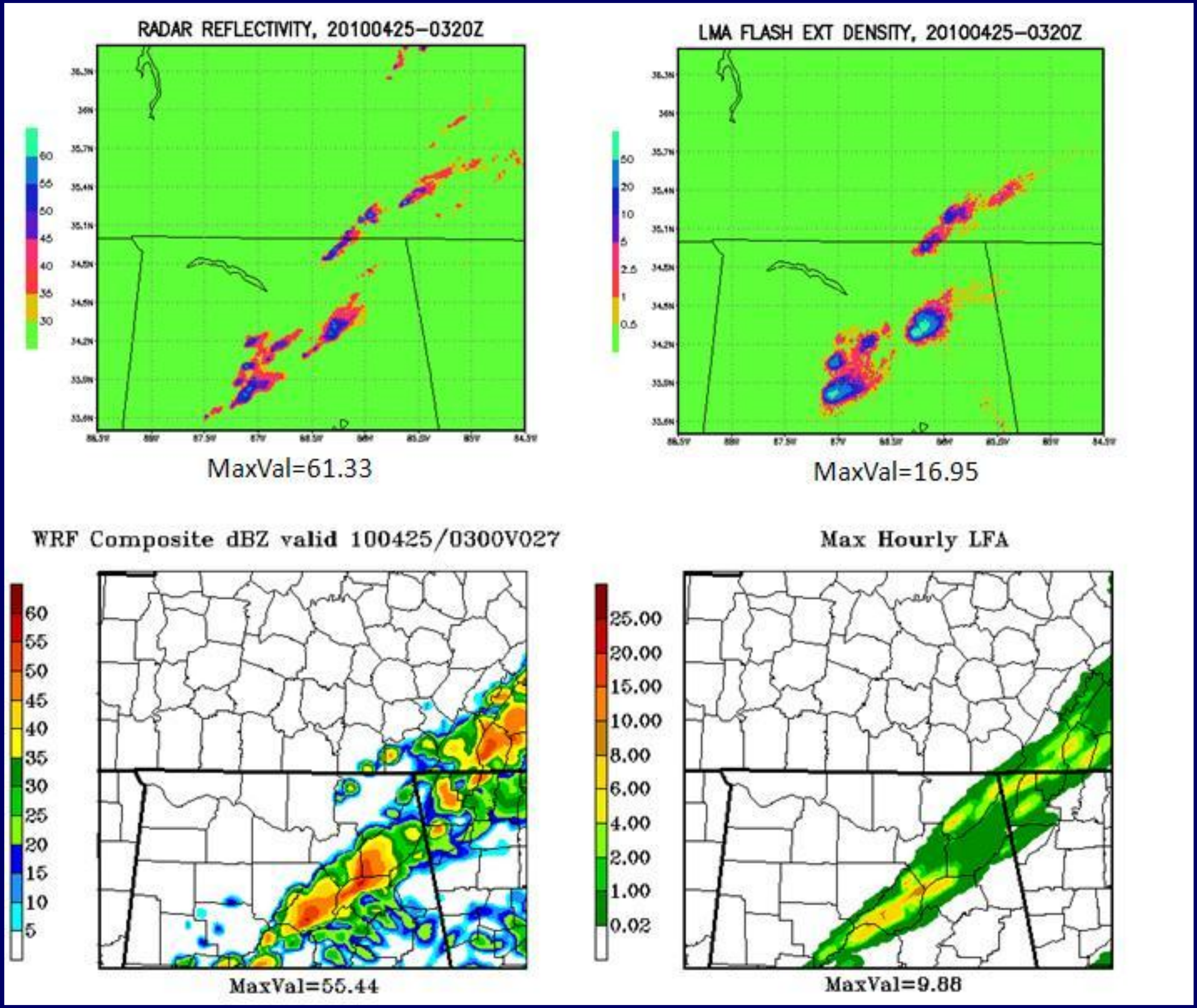
Sample of NSSL WRF output, 20101130 (see www.nssl.noaa.gov/wrf)



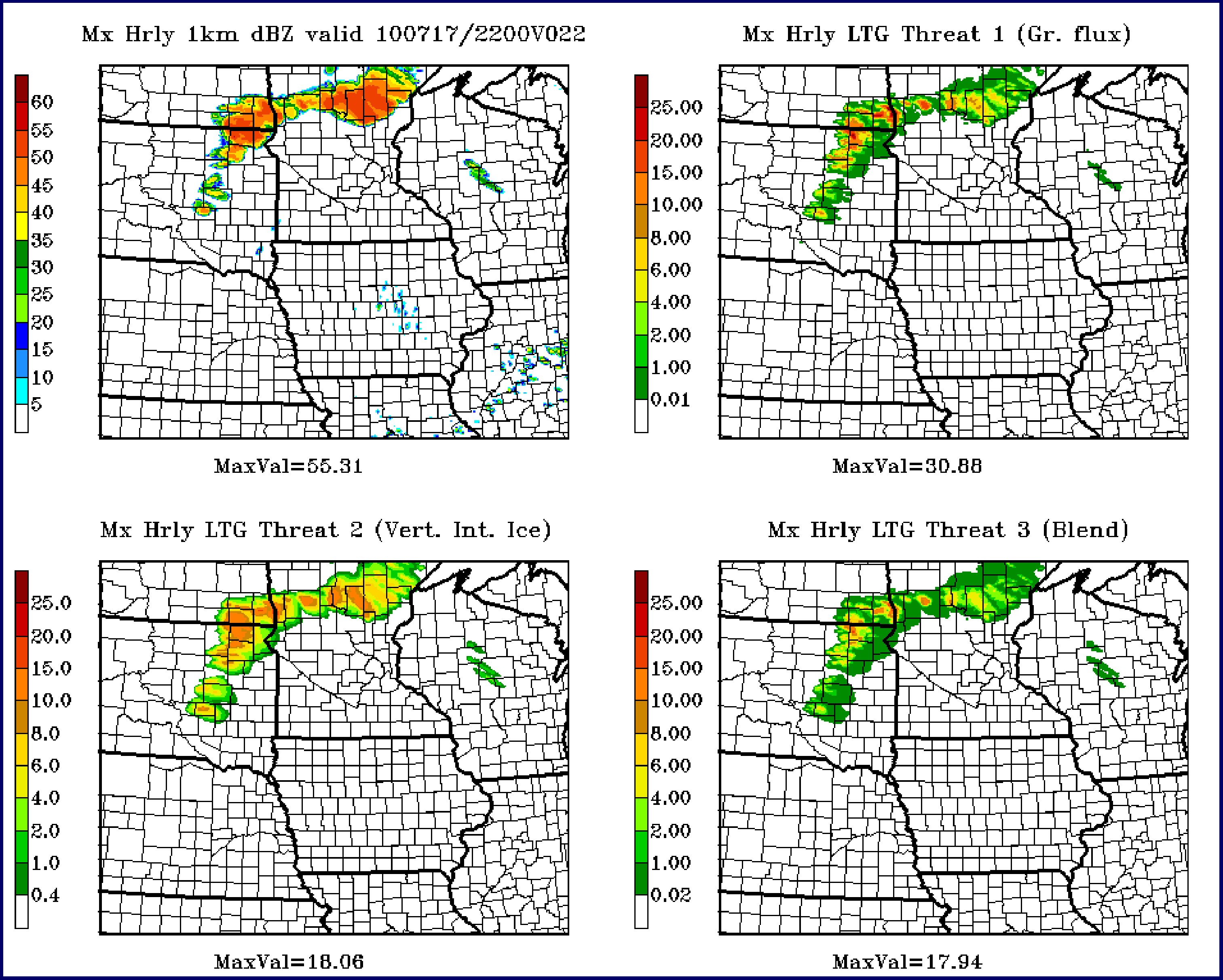
NSSL WRF data: 24 April 2010



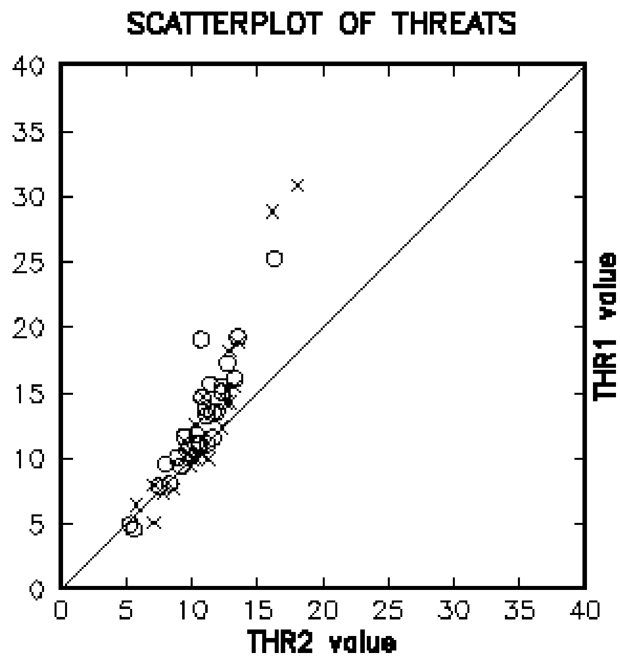
NSSL WRF data: 25 April 2010



NSSL WRF output: 17 July 2010



Scatterplot of selected NSSL WRF output for threats 1, 2 (internal consistency check)



Threats 1, 2 should cluster along diagonal; deviation at high flash rates indicates need for recalibration

Recent LFA studies, NSSL WRF, all 2010:
(examined to test robustness in larger sample of model runs)

1. Obtained NSSL daily output for full year 2010 for three regions: HUN, OUN, USA
2. HUN region examined (preliminary)
3. OUN, USA regions to be examined soon
4. 2011 data for the three regions to be examined soon
5. Preliminary inspection of results shows:
   -frequent spurious activation of LFA in wintertime (VII)
   -occasional divergent Threat 1,2 values in high FRD cases, with Threat 1 always > Threat 2 (should be equal)

Recent LFA studies, NSSL WRF, all 2010:

(examined to test robustness in larger sample of model runs)

Preliminary findings for winter weather

1. HUN region examined only (others to be examined later)
2. First findings, for ***winter weather***:
    - LFA produces 895 h (61 d) of false alarms, mostly from Threat 2, in DJFM (121 d); annualized hourly FAR=0.068 (0.42 hourly, 0.50 daily FAR in DJFM only)
    - only 262 h of false alarms from Threat 1
    - no actual winter LTG in HUN in 2010 (but see Jan 2011!)
    - if require Threat 1>0, could reduce winter FAR hrs by 70.7%, winter FAR days by 50.9%; higher Threat 1 threshold could reduce FAR even more

Recent LFA studies, NSSL WRF, all 2010:

(examined to test robustness in larger sample of model runs)

Preliminary findings for convective weather

1. HUN region examined only (others to be examined later)

2. First findings, for ***convective weather*** in HUN region, regarding ***general statistical behavior*** of LFA:

   - WRF predicts convection in HUN for ***all*** days in JJA 2010
   - LFA produces only 2 d of false alarms in JJA (FAR=0.022)
   - LFA produces zero false negative (miss) days (POD=1.00)
   - LFA has 5 false alarm days in May, 3 in September 2010

Recent LFA studies, NSSLWRF, all 2010:

(examined to test robustness in larger sample of model runs)

Preliminary findings for convective weather

3. Other findings, for ***convective weather*** in HUN region, regarding ***high FRD (>20 fl/km²/5 min) behavior*** of LFA:

- LFA produces Threat 1 FRD>20 on 27 days in JJA
- Max Threat 1=43.75, max Threat 2=20.44 on 4 Aug 2010
- WRF forecasts of strong storms tend to favor 0-6 h frame, with a weak relative bias beyond 18 h (next day's storms)
- in HUN, high FRD cases occur in summer (weak shear)

Ensemble studies, CAPS cases, 2011:

(examined to test robustness under varying grids, physics)

1. Will examine CAPS ensemble output for HUN, OUN, and USA areas soon, as data become available.
2. CAPS runs start 16 April 2011, end 10 June 2011.
3. Statistics will be accumulated on max, min, mean, SD and mean-normalized SD of ***peak LFA FRD***, using each CAPS run (19 LFA-containing members each day).
   These statistics will show degree of sensitivity of LFA output to model physics changes.
4. Additional statistics will be obtained on thresholded envelopes of LFA areal coverage, and reliability relative to actual storms (may have to use NLDN to assess this)

Future Work:

1. Examine other data from 2010, 2011 NSSL and 2011 CAPS WRF runs;
2. Compile list of intense storm cases, and use NALMA, OKLMA data to recheck calibration curves for nonlinearities, or apply changes to calibration factors; assess threshold needed for threat 1 (>0) to minimize spurious winter activation of LFA
3. Assess performance of LFA in CAPS 2011 ensembles under varying model configurations:
   - other physics schemes;
   - other combinations of hydrometeor species;
4. Assess LFA for dry summer LTG storms in w USA;
5. Examine HWRF runs (by others) to assess LFA in TCs;

Acknowledgments:

This research was first funded by the NASA Science Mission Directorate's Earth Science Division in support of the Short-term Prediction and Research Transition (SPoRT) project at Marshall Space Flight Center, Huntsville, AL, and more recently by the NOAA GOES-R R3 Program. Thanks to Mark DeMaria, Ingrid Guch, and also Gary Jedlovec, Rich Blakeslee, and Bill Koshak (NASA), for ongoing support of this research. Thanks also to Paul Krehbiel, NMT, Bill Koshak, NASA, Walt Petersen, NASA, for helpful discussions. For published paper, see:

McCaul, E. W., Jr., S. J. Goodman, K. LaCasse and D. Cecil, 2009: Forecasting lightning threat using cloud-resolving model simulations. Wea. Forecasting, 24, 709-729.